Technical Guidance for the Public Vessel Operators

Simplified Stability Test

Provided by Marine Services Unit,

New York State Office of Parks, Recreation and Historic Preservation

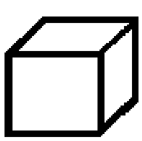
Contents

What is Stability?

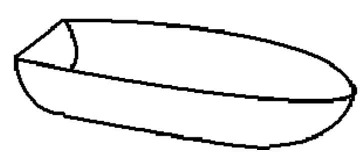
Stability is the tendency of a vessel to rotate one way or the other when forcibly inclined whether by winds and/or seas so as to resist capsizing by returning to an upright position after being heeled over. Many forces influence the stability of a vessel in the water and each vessel will reacts differently to heeling forces. Vessel operators should be aware of how the design of their vessel interacts with external forces of nature and affect its stability. If the vessel was built and loaded correctly, outside forces may cause the vessel to temporally roll from side to side, however the vessel will return to the upright by itself.

A vessel stays afloat by offsetting two forces of nature. The force of gravity attempts to push the boat down into the water, while the force of buoyancy of the water will be pushing the hull up. As long as the buoyancy is greater than the gravity, the vessel will float. How resistant it is to capsizing is dictated by how these two forces act on the vessel.

EXAMPLE OF GRAVITY -VS- BUOYANCY



1 ton of steel



1 ton of steel

If the cube of steel is placed in water it sinks. There is not enough displaced volume for the forces of buoyancy to act upon. If the cube of steel is formed into a boat’s hull and is placed in the water it will float. The larger volume of the boat's hull allows the forces of buoyancy to support the hull's weight.

The boat's hull will sink to a draft where the forces of buoyancy and the forces of gravity are equal.

THE LAWS OF BUOYANCY

1. All floating objects possess the property of buoyancy.
2. A floating object displaces a volume of water equal in weight to the weight of the body.
3. An object immersed (or floating) in water will be buoyed up by a force equal to the weight of the water displaced.

Buoyancy

The buoyancy of a vessel is determined by the shape of the immersed hull form. The larger the hull, the more weight it can support. Stability, however, is dictated by the distribution of that hull volume. For example, beam has a much larger impact on stability than length. As a general rule, the wider the hull, the more stable it is. A deeper hull will also be more stable than a shallow one. The center of buoyancy is the point at which all the vectors of the floating forces of the hull can be said to act vertically upward.

The designer usually has a great deal of control of a vessel's stability characteristics while it is still being designed. Good practice includes designing a stability margin into the hull before the vessel is built. Unfortunately, features that make a vessel more stable are often in direct conflict with the other aspects of the design. While it may be tempting to simply enlarge the beam to increase stability, this will also increase construction cost as well as increase the propulsion resistance of the hull. Increased resistance in turn drives up fuel consumption and operating costs over the life of the vessel. As with all good designs, a balance between the design criteria and operational requirements must be reached.

Weight or Force of Gravity

The hull, machinery, outfitting, and cargo load determine vessel weight. As vessel cargo load is increased, the hull will settle deeper in the water until the buoyancy equals the weight. While this may intuitively seem to increase stability, adequate

Equally important to the overall weight of the loaded vessel is how that weight is distributed. The center of gravity is the point at which the vector of the whole weight of the vessel can be said to act vertically downward. As a general rule, a lower center of gravity means a more stable vessel. A vessel with a high center of gravity is said to be "top heavy." When a vessel lists or heels to one side, the center of gravity pushes down in the direction of the list.

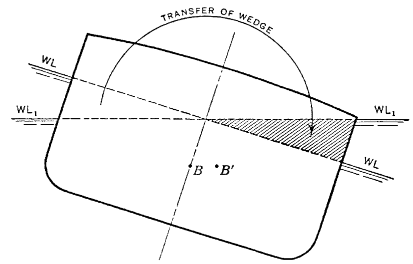
The vessel weight and center of gravity change constantly as vessel loading changes. For example, a heavy object placed high on a deck will produce a higher center of gravity - and less stability - than a load stored below deck. Similarly, removing a load from low in the vessel, such as burning fuel oil, will cause an increase in the vessel's center of gravity, thus reducing stability.

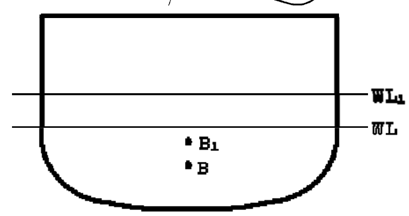
Additionally, vessels gain weight over their lifetimes as equipment is added or other changes are made to the arrangements. A good design will allow for some weight growth, but careful attention must be paid to modifications to the vessel to ensure that it continues to meet the applicable stability requirements.

Definitions

Center of Buoyancy (B) is the point at which all vertical upward forces (buoyant forces) are said to act. It is the center of the volume of the immersed portion of the vessel.   When a hull is rotated in the water the center of buoyancy will move as the shape of the underwater portion of the hull changes.

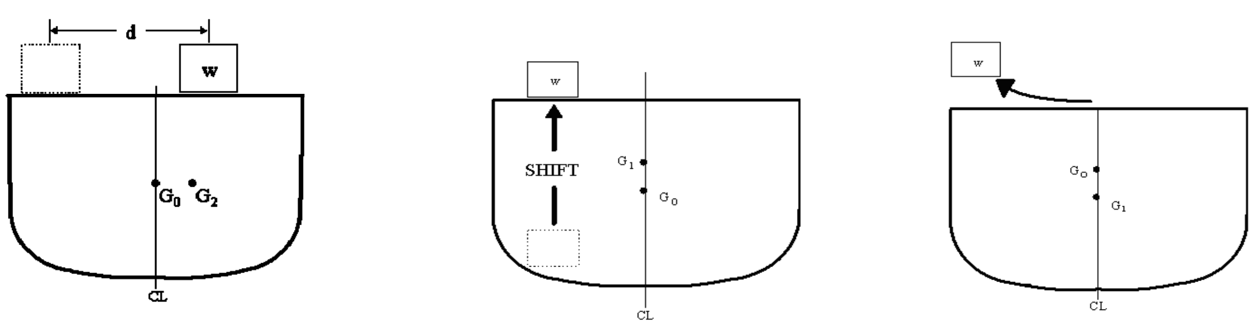
1. When the boat rolls to starboard, "B" moves to starboard, and when the boat rolls to port, "B" moves to port.
2. When the boat's hull is made heavier, the drafts increase as the boat sits deeper in the water. "B" will move up.
3. When the boat's hull is lightened, the drafts decrease as the boat sits shallower in the water. "B" will move down.
4. The Center of Buoyancy moves in the same direction as the boat's waterline.





Center of Gravity (G) is the center of the total weight of the loaded vessel. It is the point where the entire weight of the boat and its contents are concentrated. If additional excess weight is added to the boat then this point "G" will be located higher or lower depending upon if the weight was added above or below G. The position of "G" is dependent upon the distribution of weights within the boat. As the distribution of weights is altered, the position of "G" will react as follows:

1. "G" moves towards a weight addition
2. "G" moves away from a weight removal
3. "G" moves in the same direction as a weight shift



When both of these forces, Buoyancy and Gravity are equally oppose to each other from directly opposite directions then the boat is said to be "At Rest" or upright.

Heel is the temporary tilting of a vessel from side to side. If this tilt becomes permanent it is then called a List

List is a permanent tilting of a vessel to one side or the other.

Freeboard is the distance between the water and the working deck of the vessel. If the deck edge goes under water when the vessel heels, the danger of capsizing is increased. An overloaded vessel will have too low a freeboard, and the deck may submerge with even a light heel caused by wind or water conditions.

Displacement is the weight of the volume of water that is displaced by the underwater portion of the hull is equal to the weight of the boat. This is known as a boat's displacement. The unit of measurement for displacement is the Long Ton (1 LT = 2240 LBS).

Force is a push or pull that tends to produce motion or a change in motion. Units are expressed in tons, pounds, Newtons, etc. Parallel forces may be mathematically summed to produce one "Net Force" considered to act through one point.

Weight is the force of gravity acting on a body. This force acts towards the center of the earth. Units are expressed in tons, pounds, kilograms, etc.

Moment is the tendency of a force to produce a rotation about a pivot point. This works like a torque wrench acting on a bolt. Units are expressed in foot tons, Newton meters, etc.

Free surface effect influences the stability of a vessel. When a vessel with full tanks heels over, the tank's center of gravity does not change, so it does not affect the vessel's stability. However, water on deck, liquids in holds, bilge water, and partially filled tanks will cause a shift of the liquid with the movement of the boat. When this happens, the center of gravity also shifts, making the vessel less stable. This "free surface effect" reduces stability and increases the danger of capsizing.

Initial stability is the stability of a boat in the range from 0% to between 7% and 10% of inclination.

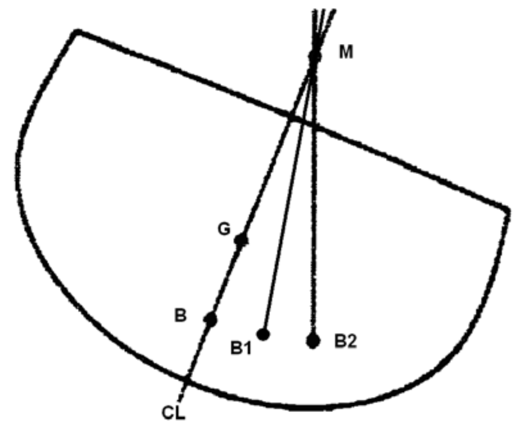
Overall stability is a general measure of a boat's ability to resist capsizing in a given condition of loading.

Dynamic stability is the work done in heeling a boat to a given angle of heel.

Keel (K) is the base line reference point from which all other reference point measurements are compared.

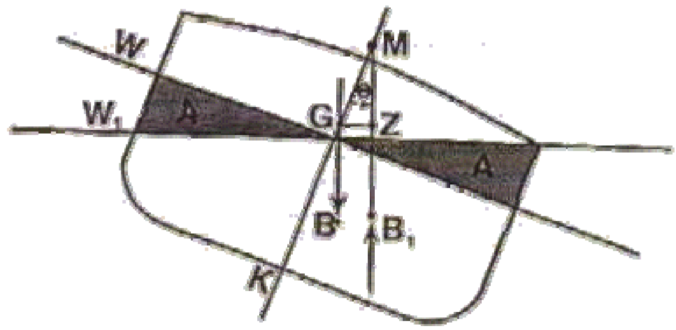
Metacenter (M) is a point where the lines of buoyant forces intersect as the boat is inclined through small angles of heel. As the boat is inclined, the center of buoyancy moves in an arc as it continues to seek the geometric center of the underwater hull body. The position of the metacenter is a function of the position of the center of buoyancy, thus it is a function of the displacement of the boat. The position of "M" moves as follows:

1. As the Center of Buoyancy moves up, the Metacenter moves down.
2. As the Center of Buoyancy moves down, the Metacenter moves up.



Stability at Work

If an outside force such as a wave caused this boat to heel over to one side, And if the weight of the boat and its contents has not changed, or shifted, then the center of gravity (G) will remain in place. But look at the "B", it moved in the direction of the lower side. This point is now the center of Buoyancy and the upward forces of Buoyancy will seem to push harder on this lower side. The result will be to return the hull to its upright position.

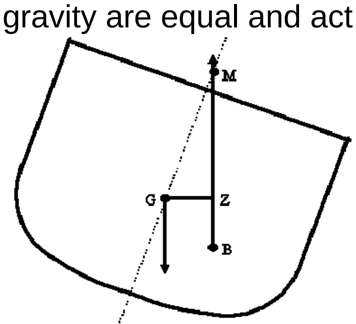


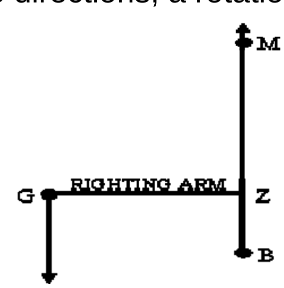
The Metacenter "M" is a point near the centerline of the boat at rest. It is a point that will normally be stationary and directly over the point of buoyancy regardless of which side "B" moves. If you consider "B" as the ball at the bottom of a pendulum then "M" is the connecting point from which that pendulum swings. The Metacentric Height then is the distance between the center of gravity "G" and the metacenter "M" and is simply called "GM".

The GM is crucial to stability. The further apart that "G" and "M" become, the more stable the boat and the quicker it will right itself. A long GM also causes an uncomfortable quick snapping roll. To provide a more comfortable ride, most passenger boats are built with a shorter GM. This will allow the vessel to slowly recover. Too little GM results in a vessel with a long, slow roll that, while comfortable, could lead to capsizing. As long as the weight of a vessel, and the location of that weight, remains constant, and then the center of gravity would not move.

THE STABILITY TRIANGLE

When a boat is inclined, the center of buoyancy shifts off centerline while the center of gravity remains in the same location. Since the forces of buoyancy and gravity are equal and act along parallel lines, but in opposite directions, a rotation





is developed. This is called a couple, two moments acting simultaneously to produce rotation. This rotation returns the boat to where the forces of buoyancy and gravity balance out.

The distance between the forces of buoyancy and gravity is known as the boat's righting arm. As shown above, the righting arm is a perpendicular line drawn from the center of gravity to the point of intersection on the force of buoyancy line.
For small angles of heel (0° through 7° to 10°, the metacenter doesn't move), the value for the boat's righting arm (GZ) may be found by using the trigonometry equation of:

$$GZ = GM \times \sin\theta$$

With initial stability (0° through 7° to 10°) the metacenter does not move, and the Sine function is almost linear (a straight line.) Therefore, the size of the boat's Righting Arm, GZ, is directly proportional to the size of the boat's Metacentric Height, GM. Thus, GM is a good measure of the boat's initial stability.

RIGHTING MOMENT (RM)

The Righting Moment is the best measure of a boat's overall stability. It describes the boat's true tendency to resist inclination and return to equilibrium. The Righting Moment is equal to the boat's Righting Arm multiplied by the boat's displacement.

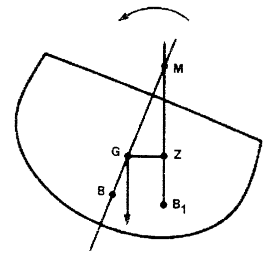
$$RM = GZ \times W_F$$

As long as the G remains below the M then there will be available Righting moment to right the vessel.   Once G is centered over the M then the vessel will capsize.

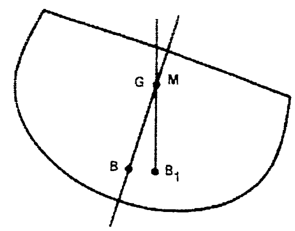
Righting energy is the term used to describe a vessel's ability to right itself after being heeled over. A properly-loaded vessel should have positive righting energy to a heel of at least 50 degrees. The magnitude of the largest righting arm is also an indication of a vessel's stability.

STABILITY CONDITIONS

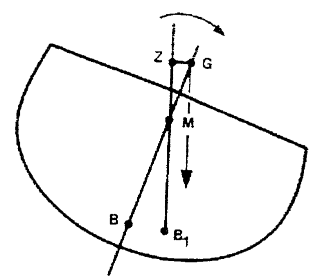
The positions of Gravity and the Metacenter will indicate the initial stability of a boat. Following damage, the boat will assume one of the following three stability conditions:



POSITIVE STABILITY
The metacenter is located above the boat's center of gravity. As the boat is inclined, Righting Arms are created which tend to return the boat to its original, vertical position.



NEUTRAL STABILITY
The metacenter and the boat's center of gravity are in the same location. As the boat is inclined, no Righting Arms are created (until M starts to move below G after the boat is inclined past 7º-10º).



NEGATIVE STABILITY
The boat's center of gravity is located above the metacenter. As the boat is inclined, negative Righting Arms (called upsetting arms) are created which tend to capsize the boat.

Weight Movements

Because of the relationship between weight and buoyancy of a given hull shape, both GM and righting energy vary significantly with the weight and center of gravity of the loaded vessel. This means that how a vessel is loaded has the largest impact on the stability of the vessel.

Adding a load
Adding weight above a boat's center of gravity will change its stability. If the center of gravity is raised too much, the boat will become unstable. As a result, less force is required to capsize the vessel.

Removal of a load
Removal of weight from below the center of gravity also decreases stability. The center of gravity will rise to a higher level decreasing the GM of the vessel resulting in a vessel with a quicker roll period.

Shifting a load
Shifting weights vertically, no matter where onboard it is, will always cause the boat's center of gravity to move in the same direction as the weight shift. When you raise a weight it will cause a rise in G, decreasing your stability. This is the reason passenger limits are put on upper decks of public vessels. The more passenger weight kept on the main deck the better the stability of the boat.

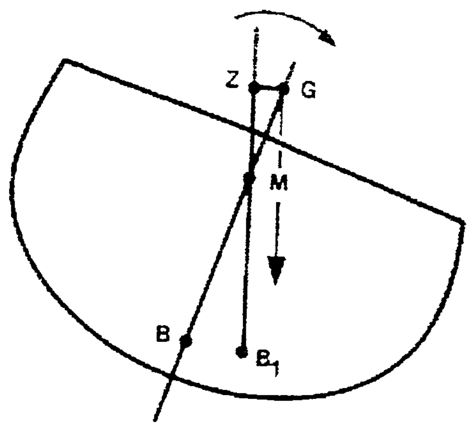
Shifting weight horizontally, adding a weight off centerline, will always cause the boat's center of gravity to move in the same direction as the weight shift. The boat's center of gravity will move off centerline, the boat will develop a list. A weight shift causing the boat's center of gravity to move off centerline will always reduce the stability of the boat.

Whenever weight is added, moved or removed a boat, the boat's center of gravity rarely moves in only one direction. Fortunately, the effects are cumulative

Damage Control

The previous pages have discussed vessel stability characteristics in the intact state. They also apply to a damaged vessel. However, the buoyant force and center of buoyancy of the damaged hull will differ significantly from that of the intact hull, depending on hull compartmentation as well as the location and extent of damage.

As the unexpected excess weight of flooding water is added, the boat's center of gravity will initially decrease and the vessel will seem to become stable. At some point in time the center of gravity will start rises. Once it reaches the metacenter and goes beyond the boat will capsize. This new location of the downward force of gravity will now fight against the righting tendency of the new point of buoyancy that had shifted previously. The result is that the boat will no longer return to the upright..



If an area flooded with the water is only partially filled, and there is no restriction to the side-to-side movement of the water, the result can be devastating This free movement or sudden shifting of water is called “Free Surface Effect” and has a major effect on a vessel's stability.
If the area is completely flooded or if there are restricting boundaries to act as baffles then the water is no longer subject to Free Surface Effect.

Also, as the boat develops a list, its center of gravity may move in the same direction as the point of buoyancy if there is also a corresponding shift in weight as in the diagram.

A good operational practice is to minimize free surface effect by dividing tanks with baffles and fluid cargo holds with bulkheads and by keeping the number of partially filled tanks and holds to an absolute minimum.

Vessel Stability – Warning Signs, Precautions

The most important factors in preventing a boat from capsizing are a well-designed, maintained, and loaded vessel and an experienced operator and crew. Preventing an unstable vessel condition and being able to recognize the warning signs when such a condition does occur can save lives. You should be on constant watch for loss of stability.

- ✓ A well-designed vessel will resist capsizing or foundering in severe conditions if it is operated properly. To reduce the likelihood of these incidents, keep these rules in mind:
- ✓ Be aware of external forces – wind, waves, and water depth. Always check the weather forecast before departure. Avoid rough weather conditions.
- ✓ Don't overload your vessel. Be aware of the amount of weight added to your vessel and available freeboard. Distribute the passengers and cargo evenly.
- ✓ Partially filled water ballast and fuel tanks contribute to instability. Free surface liquids must be contained so their influence will not upset the balance of your vessel.
- ✓ Prevent water from entering the interior of your vessel by keeping hatches, doors, and windows closed, as practicable, when underway. Regular maintenance of gaskets and fastening devices will help to ensure water tightness.
- ✓ Any water shipped on board must be removed as quickly as possible. Scuppers and drains must meet design criteria and be kept in good working order.
- ✓ Adjust course, speed, or both as practicable to minimize vessel motion, rolling in particular.
- ✓ Avoid sharp turns or turns at high speed when loss of stability is possible.

Stability Warning Signs

- ✓ Observe the stability and roll of your boat. Make sure the vessel's movement and reaction to sea conditions is normal, steady, and safe.
- ✓ Check to make sure your boat is visibly stable before you leave the dock. It should not be listing to port or starboard or trimmed excessively by the bow or stern.
- ✓ Observe freeboard and check for flooding. A flooded vessel may appear stable when it is in fact not.
- ✓ Make sure the passengers remains seated during the voyage.
- ✓ Make sure that bilge level alarms are operational. Unusual operation of bilge pumps may indicate an excessive amount of water is entering the interior of the vessel.

A combination of prevention efforts and awareness of the warning signs of instability, along with operator knowledge, can accomplish a great deal in reducing instability and capsizing.

The Stability Tests

The USCG has created two simplified stability test that will show the inherent stability a vessel possesses. The USCG limits the types of vessels that may use the simplified stability test procedures. The MSU will shall apply these guidelines to all vessels carrying more than 20 passengers and under 65 feet or those whose stability, in the judgment of the MSU, require an evaluation.

Simplified Stability Test for Monohull Vessels: The Coast guard originally developed the simplified stability proof test currently found in reference (a) in the 1950s. The Coast Guard created this tool to evaluate the stability of monohull small passenger vessels. The Coast Guard wrote the regulations in 46 CFR 178.3 10 to apply to certain monohull small passenger vessels defined as:

- ✓ Less than 65’ in length
- ✓ Carrying 150 or less passengers
- ✓ Carrying no more than 12 passengers on an international voyage
- ✓ Having only one hull
- ✓ Having no more than I deck above the bulkhead deck, not including a pilothouse, and
- ✓ If a sailing vessel, meets the restrictions in 46 CFR 178.325.

Simplified Stability Test for Pontoon Vessels: The Coast Guard created the pontoon simplified stability proof test to evaluate the stability of lightweight pontoon small passenger vessels. The Coast Guard wrote the regulations in 46 CFR 178.340 to apply to certain pontoon small passenger vessels defined as:

- ✓ Less than 65’ in length
- ✓ Carrying 49 or less passengers
- ✓ Operating only on protected waters
- ✓ Floating on only 2 separate, fully enclosed symmetric pontoons
- ✓ With no machinery or tankage in the pontoons
- ✓ With only one deck accessible to passengers, and the accessible portion of the deck does not extend outboard of the pontoons at their outermost point, and
- ✓ Constructed with the deck no higher than 6 inches above the top of the pontoons.

Other Hull Forms: Since the development of the simplified stability proof test and the pontoon simplified stability proof test, The USCG has seen the use of other hull forms for small passenger vessels. These other hull forms include catamarans, trimarans, and other hybrid multi-hull types. Catamarans differ from pontoon vessels in that the hulls often contain machinery, tankage, and piping, the hulls may be asymmetric, and the hulls are often integral with the deck above. These vessels shall not perform the monohull simplified stability proof test or the pontoon simplified stability proof test. These vessels shall submit stability calculations to the Marine Service Unit for review and approval.

If the Marine Services Unit questions the stability of the vessel based on the results of the simplified stability test the vessel owner must provide calculations to the Marine Services Unit showing the vessel meets the applicable stability criteria of 46 CFR Subchapter “S” in each condition of loading and operation.

Stability Tests

When bring a passenger boat into service on New York State Waters you must be able to present to the Marine Service Unit stability information of your boat. Lacking a stability booklet provided by a naval architect, or a USCG Coast Guard Stability Letter you will have to subject your vessel to the whims of this office.

To find your boat's passenger carrying capacity you will be asked to perform a simplified stability test or inclining experiment on your boat. This testing will be performed by a qualified individual of your choice that has been approved by this office. After changing the vessel's displacement by either addition or removal of weight you may be require to perform this test again.

If you are required to have a simplified stability test you will either submit plans of the passenger carrying deck or have a member of the marine Service Unit measure your vessel. Once measurements are made MSU will inform you of the maximum person load your vessel can carry. You must then acquire the services of an approved qualified person to perform and report the finding of the test.

For the test we will add weight to your vessel, on its centerline, comparable to the maximum number of person you would carry. This weight must be raised off the deck to simulate the center of gravity of the passengers. After the weight has been added a certain amount of weight is moved to either the port or starboard side, on each deck that you carry passengers to see how the vessel will react to a large heeling moment. If half the freeboard does not disappear and the angle of heel is less than 7 to 14 degrees, the boat ***may*** be certified for the weight it was inclined at.

In order to facilitate the test you will provide barrels for the water that will be used as the test weight. Blocks and timbers will be used to raise the barrels and a high capacity pump to fill the barrels. From the plans that you submitted MSU will calculate the number of person allowed to be carried on board. You will have to have one barrel for each 2.6 persons carried, based on a 55 gallon barrel. Concrete blocks and 4x4 timbers will be used to raise these barrels. Plan on having 2 4x4’s and 5 concrete blocks for every three barrels that you will use.

Example, 25 passenger boat will need 9.6 barrels so plan on 10 barrels and 8 4x4’s and 20 concrete blocks.

On the day of the test MSU and your qualified person will:

1. Measure deck areas, aisle, obstructions (bars and non moveable items), and measure rail length if there is an outside passage that people can stand during the voyage.

2. Make diagrams of profile of boat and floor plans of each deck and mark measurements.
3. Take fore, aft and midship's freeboard measurements before starting.
4. Take weight measurements of:
    a. People that will stay on boat while freeboard reading are taken
    b. Blocks
    c. Timbers or planks
5. Determine where the freeboard reading is to be taken.
6. Figure shift of weight distance.
7. Figure weights to be placed on each deck.
8. Figure movement of weights.
9. Record number of barrels emptied and number moved.

When the test is concluded the qualified person will complete the testing procedure forms and forward them to MSU for review. Once MSU has received and reviewed the paperwork a determination on persons allowed to be carried on board will be made and the owner will be notified in writing of this decision.

Minimum Qualifications for Individuals Employed to Conduct Vessel Stability Testing

(Interested individuals must submit credentials, resume or work history to the Marine Services Unit for approval prior to undertaking stability work.)

Naval Architect or Marine Engineer (Credentialed)

Or;

Boat Builder or Manufacturer having 10 of more years experience in building vessels comparable in size to vessel to be tested as well as knowledgeable of and experienced in conducting Coast Guard required stability tests.

Or;

Coast Guard Officer (active or retired) having career experience (Officer in Charge) in the area of commercial marine inspection (Marine Safety Office) and having knowledge of and experience in conducting Coast Guard required stability tests.

Colleges offering courses in Naval Architecture
You may want to contact their alumni or placement offices for possible naval architects.

California Maritime Academy
California State: Long Beach
Florida Atlantic University
Florida Institute of Technology
Maine Maritime Academy
Massachusetts Institute of Technology
Massachusetts Maritime Academy
Memorial University of Newfoundland
SUNY Maritime College
Stevens Institute
Texas A & M University
Texas A & M University at Galveston
U.S. Coast Guard Academy
U.S. Merchant Marine Academy
U.S. Naval Academy
University of British Columbia in Vancouver
University of California-Berkeley
University of Michigan
University of New Orleans
Virginia Polytechnic Institute & State University
Webb Institute
University of Wisconsin

Professional publications that may have advertise naval architect services

Marine Engineer's Log	www.marinelog.com
Work Boat Magazine	www.workboat.com
Professional Boat Builder	www.proboat.com

Professional organizations that can direct you to a naval architect

SNAME Society of Naval Architects and Marine Engineers www.sname.org

ASNE American Society of Naval Engineers

www.navalengineers.or

g/

American Boat and Yacht Council www.abyc.com

Alternate certifications

ABYC's Westlawn Institute of Marine Technology – though they do not grant a college degree, if a graduate can support their work in the field of ship design and construction with similar sized vessels that have gone through a USCG certification process and the graduate has performed several simplified and small boat stability tests that has been used to issue a USCG stability letter, this office may recognize the person's credentials

Professional boat builder, no college degree – if a boat builder has designed and built a sufficient number of vessels, of the same or more capacity as the vessel you have, that have gone through a USCG certification process and the builder has experience conducting stability tests, simplified and stability that has been used to issue a USCG stability letter, this office may recognize the builder's credentials

Insert Simplified Stability Test, Mono Hull and Pontoon Here